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Analysis of multi-factors affecting the performance of Nigeria's refineries: a systems thinking approach.

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A systems thinking approach to the analysis of multiple factors affecting the performance of Nigeria's refineries.

Abstract

Purpose

The challenges facing the productivity of Nigeria's refineries has generated much academic discourse. This study was carried out to develop a causal loop model showing the interrelationships of the multiple factors driving the poor performance of the refineries. Using a framework of political, economic, social, and technical (PEST) factors, the developed model helped identify leverage points for policy intervention in the system.

Design/methodology/approach

A mixed-method approach was adopted to collect quantitative data from 118 refinery workers and qualitative data from 14 participants polled from the various Nigerian National Petroleum Corporation (NNPC) subsidiaries. The quantitative data was analysed through Structural Equation Modelling (SEM) to prioritise the more significant factors, while the qualitative data were analysed by content analysis to further validate the questionnaire findings and provide clearer contexts for the operationalisation of the factors.

Findings

The structural equation model identified several PEST factors such as government interference, political indecision, funding issues, spare parts costs, pipeline vandalism, oil theft, maintenance issues as some of the significant factors affecting the performance of the refineries. The interviews validated these findings and provided richer contexts on how these factors operate within the system. A causal loop model was developed based on these findings to identify key leverage points upon which policy intervention through best practice, management autonomy and stakeholder satisfaction were proposed to address these challenges.

Practical implications

The study uncovers that the factors which affect the performance of the refineries have significant multiple interrelationships, the understanding of which are crucial for developing effective solutions by policymakers.

Originality/value

This study is the first to apply the concept of systems thinking together with structural equation modelling to analyse the causal interrelationships amongst the significant factors affecting the performance of NNPC refineries. The causal loop model developed by the study provided pathway to improve future practice in refinery management in Nigeria through policy intervention.

Keywords: *Systems thinking; Nigerian refineries; Structural equation modelling, Causal loop diagrams; Policies.*

1.0 Introduction

The problems of the Nigerian petroleum refining industry have been well articulated by various scholars (Ogbuigwe, 2018; Akinola, 2018; Wapner, 2017 and Turner, 1977). Given the apparent opportunities in this industry with more than 600,000-bpd local demand for refined petroleum products (RPPs) (Iheukwumere et al., 2020), it would be logical to expect the performance of Nigeria's refining industry to be at its best. Unfortunately, the sub-optimal performance of these state-owned refineries and the inability of the Nigerian government to revitalise the industry over a period of more than two decades, have continued to confound researchers (Akinola, 2018; Adeosun and Oluleye, 2017; Siddig et al., 2014 and Osimiri, 2001).

Nigeria has four state-owned refineries with a total installed capacity of 445,000 barrels per stream day (BPSD), which are strategically located across the country. These refineries are operated by the Nigerian National Petroleum Corporation (NNPC) as subsidiaries under its business structure. The refineries include the two Port Harcourt refineries (PHRC I and II) with current capacities of 60,000-bpsd and 150,000-bpsd, respectively; Warri refinery (WRPC) with a 125,000-bpsd capacity and the Kaduna refinery (KRPC) with a capacity of 110,000-bpsd.

Nigeria ranks amongst the top countries in Africa with significant oil reserves, precisely some 38 billion barrels of proven oil deposits as at the end of 2018, only second to Libya (BP Statistical Review, 2019 and EIA, 2019). The country is also the largest producer of crude oil in Africa with an average production in the range of 1.8 – 2.5 million barrels per day (bpd) (EIA, 2020, and BP Statistical Review, 2019). The sale of crude oil generates much of the government's income, accounting for more than 90% of its foreign exchange earnings, and more than 80% of government's total revenue (Ogbuigwe, 2018 and Akinola, 2018). However, while the contribution of the upstream oil sector accounts for up to 10% of Nigeria's GDP, that of the downstream sector, mainly the refining sector accounts for less than 1% of the GDP (Omoriege, 2019; Watts, 2004 and Wapner, 2017). This disparity is primarily due to the inefficiency of the refining sector which has mostly operated below 20% since 2010 (Iheukwumere et al., 2021).

This productivity gap has not only contributed to the higher cost of living in the country but has also led to the regular imports of more than 80% of the country's domestic demand for RPPs to the detriment of the Nigerian economy (Nwaoha et al., 2018 and Apere, 2017). This development has led many researchers to investigate the factors generating such a level of inefficiency (Ogbuigwe, 2018; Adeosun and Oluleye, 2017; Siddig et al., 2014; Iwayemi, 2008). Consequently, some of these studies have uncovered several factors, which hardly act independently in driving inefficiency in this system. In addition, the scale of decay across Nigeria's petroleum refining industry has been shown to incorporate multiple factors which have defied short-term sectoral interventions (Igboanugo et al., 2016 and Iheukwumere at al., 2021).

The objective of this study is to utilise the concept of systems thinking to develop a causal loop model showing the interrelationships of the significant factors driving the systemic failures across Nigeria's refining sector. It seeks to bridge a gap in knowledge by providing a holistic approach to the analysis of the causalities of the significant factors affecting the productivity of the refineries. This is done with a view of providing a pathway for policy recommendations using identifiable leverage points in the model to improve future practice in the management of refineries.

2.0 Challenges of NNPC refineries

According to the information published on the NNPC's website (nnpcgroup.com), the NNPC Group is headed by a Group Managing Director (GMD) who oversees its Corporate Headquarters, five Autonomous Business Units (ABUs) and the Corporate Services Directorate. The ABUs and the Corporate Service Directorate are each headed by Chief Operating Officers, except for Finance and Accounts, which is headed by a Chief Finance Officer. The organisational structure of the NNPC Group is as shown in Figure 1.

>>>Insert Figure 1<<<

Figure 1 shows that the NNPC ABUs and CSUs are further divided into various subsidiaries with different functions. However, the relevant subsidiaries in this study are the refineries (PHRC, WRPC and KRPC). It is important to note that the two Port Harcourt refineries (PHRC I and II) are classed as one in this study (PHRC) as both refinery facilities are co-located and are managed as a single entity.

Iheukwumere et al. (2021) identified the significant performance challenges of the NNPC refineries and showed that these challenges cut across political, economic, social, and technical (PEST) factors. This study, therefore, builds on this PEST framework to investigate the interrelationships amongst the sub-category PEST factors affecting refinery productivity in Nigeria.

These PEST factors were sourced from the literature surrounding the productivity challenges of the refineries. In context, Political factors (P) deal with the direct or indirect government interferences on the refineries, consequences of political indecisions, legislative issues, political will, managerial appointments as well as government funding of the refineries (Ogbuigwe, 2018; Akinola, 2018; Chikwem, 2016, Ambituuni et al., 2015 and Iwayemi, 2008). Economic factors (E) refer to the economic and monetary policies and conditions which impact on the refineries' performance (Kennedy-Darlington et al., 2008; Akinola, 2018; Eti et al., 2004/2006, and Wapner, 2017). Social factors (S) involve the social, cultural, and behavioural issues with direct or indirect consequences on the productivity and performance of the refineries (Siddig et al., 2014; Onuoha, 2008; Boris, 2015 and Iwayemi, 2008). Whereas the technical factors (T) incorporate issues regarding maintenance of the facilities, efficiency of product movements into and out of the facilities, personnel skills and training required to manage the refineries (Ambituuni, 2014; Et et al., 2006; Chima et al., 2002, Turner, 1977; Bazilian and Onyeji, 2012).

2.1 Categories of the PEST challenges for the NNPC refineries.

The details of these challenges may be summarised according to the following sub-headings:

2.1.1 Political factors

The Nigerian refineries are owned by the federal government of Nigeria through its national oil company – the Nigerian National Petroleum Corporation (NNPC). The NNPC itself is controlled by the federal ministry of petroleum resources, which is usually headed by a Minister who reports to the Nigerian President. Wapner (2017) reports that there is a multi-layer of bureaucratic channels through which most key decisions regarding NNPC refineries must pass before obtaining federal government approval. This process systematically introduces unnecessary delays and complicates simple issues, thereby preventing timely decision-making (Akinola, 2018). This view is consistent with the assertions of Ogbuigwe (2018) who opined that since the refineries lost their management autonomy in the early 1990s, funding issues have become a major concern as the refineries now rely on politicians to obtain approval for needed funds. In addition, the political indecision associated with the prolonged delay in the passage of the Petroleum Industry Bill has been reported to prevent needed reforms (Iheukwumere et al., 2021 and Adeosun and Oluleye, 2017). Also, Onyekakeyah (2020), notes that political appointments within the governance structure of the NNPC and its subsidiaries are sometimes based on nepotism rather than competence and experience and do not always produce the most capable persons to lead the organisation. To this end, it was considered necessary to include these factors in the questionnaire to investigate their significance.

2.1.2 Economic factors

The NNPC refineries are major economic assets of the federal government of Nigeria. Table 1 outlines the costs and other details of the construction of these refineries. Consequently, it would be logical for the government to expect some returns from these refineries either in terms of monetary profits or national energy security. However, few of these expected benefits can be argued to have been achieved given the prolonged poor performance of the refineries (Akinola 2018 and Badmus et al., 2012).

<<<Insert Table 1>>>

Some of the economic factors that have contributed to difficulties in maintaining the refineries include high cost of spare parts, volatile exchange rates, low or non-existent profit margins and problems associated with subsidy issues in Nigeria (Akinola, 2018; Ogbuiwe, 2018; and Babatunde, 2015). Implicit in some arguments is the notion that if the money Nigeria spends on petroleum subsidies were used to fix the refineries, the country would save money through reduced imports of RPPs, which would in turn help re-channel these resources to other developmental projects (Adeosun and Oluleye, 2017 and Siddig et al., 2014). Petroleum subsidy payments amounted to US $1.87 billion in 2018 alone (Udo, 2020). This implies that Nigeria spent more than US $5 million per day in 2018 to subsidise imported refined petroleum products. Studies suggest this condition is unsustainable and would in the long run lead to the reduction of available capital for government to fix public infrastructure, including the refineries (Iheukwumere et al., 2020/2021 and Iwayemi, 2008). However, it is uncertain to what extent subsidy payments directly affect government infrastructure spending and whether this is a case of a lack of political will. Hence, these factors were investigated by this study via the questionnaire survey.

2.1.3 Social factors

Akinola (2018), Boris (2015) and Ikelegbe (2005) identified important social issues which have contributed to the inability of NNPC refineries to perform optimally. These problems include attacks on oil pipelines conveying products to and from the refineries. These acts which are carried out by the local youths are done either to steal refined petroleum products for sale or syphon crude oil for illegal refining purposes. These actions are aided by weaknesses in the pipeline security system and have also proven detrimental to the ecological environment of Nigeria's delta area (Obenade and Amangabara, 2014).

Collusion and sabotage from security operatives as well as industry and community stakeholders is said to have led to the loss of about 250,000 barrels of crude oil between 2009 – 2010 (Akinola, 2018). Overall, the monetary value of losses incurred due to bunkering activities between the same 2009 to 2010 is estimated at US $10.9 billon (Akinola, 2018). Some of these losses comprise pipeline breaches with Salami (2013) reporting that a total of 1,498 petroleum pipeline breaches occurred in 2012 alone. There has, however, been some positive steps by the Nigerian security in checkmating the excesses of these oil thieves. For example, Boris (2015) and Utebor (2013) outlines some of the success of the Nigerian Joint Task Force in combating the spate of illegal refining in the Niger Delta. Unfortunately, these successes are yet to completely end this ugly trend in the region as sporadic incidences of this kind continue to be reported. Hence these factors were included in the questionnaire to determine their current impacts on the refineries.

2.1.4 Technical factors

Technical issues are one of the most important factors limiting the performance of NNPC refineries in Nigeria. Aside from the oldest Port Harcourt refinery (PHRC I), which is a simple hydro-skimming refinery, the other three NNPC refineries; Port Harcourt (PHRC II), Kaduna (KRPC) and Warri (WRPC) are complex cracking refineries with fluid catalytic crackers (FCCs). However, none of the refineries have coking capabilities as most modern refineries do (Cross et al., 2013). It is important to note that a lot of the equipment components in these refineries have become outdated and as such present performance challenges (Badmus et al., 2012 and Eti et al., 2006).

Other technical factors which present challenges for the refineries include maintenance problems, a lack of adequate technical knowhow, limited plant capacity, ageing refinery plants and problems associated with feedstock supply (Siddig et al., 2014; Ambitunni, 2014, Eti et al., 2006; and Iwayemi, 2008;). According to Eti et al. (2006), there is a culture of reactive maintenance across Nigerian industries, especially within the government refineries. Whereas a proactive maintenance culture should reduce the need for reactive maintenance, there is, however, a disproportionate lack of awareness of the effectiveness of proactive maintenance across Nigerian industries. There are various forms of maintenance programmes under the proactive and the reactive categories, which are typical for industries like oil refineries. Azadeh and Zadeh (2016) provided an overview of some of the important maintenance policies (Figure 2).

>>>>Insert Figure 2>>>>

While terminologies for some of these maintenance types (Figure 2) may vary across industry, the condition-based maintenance approach under the proactive category has been shown to be cost-effective as it focuses on replacing or rehabilitating equipment parts where failure is judged to be imminent (Azadeh and Zadeh, 2016; and Eti et al. 2006).

Unfortunately, the lack of regular maintenance across NNPC refineries has contributed to the ageing and deterioration of refinery parts, which reduces equipment reliability and in turn increases the frequency of plant breakdowns (Iheukwumere et al., 2021 and Ogbuigwe, 2018). In addition, the lack of adequate technical knowhow appears to further limit the ability of Nigerian engineers at the refineries to carry out major maintenance operations independently (Akinola, 2018 and Eti et al., 2006). The extent of impact of these factors on the refineries were also investigated via the survey questionnaire. Table 2, which is adapted from Iheukwumere et al. (2021) is a summary of the PEST factors identified from the literature.

>>>Insert Table 2<<<

Using the identified PEST factors from Table 2, the performance gaps across the NNPC refineries can be mapped onto a cause-and-effect diagram (Figure 3) to help appreciate the network of interconnecting factors.

>>>Insert Figure 3<<<

Figure 3 shows the various subcategory PEST factors on a cause-and-effect diagram driving the performance gaps across the refineries.

3.0 Performance Gaps

The performance of most refineries is measured in terms of their efficiency. Al-Najjar and Al-Jaybajy (2012) applied the concept of Data Envelopment Analysis (DEA) to measure the efficiency of an oil refinery as the difference between best practice and observed units. In this approach, best practice was related to organisational, national, and international standards. Technically, the measurement of efficiency was established by the work of Farrell (1957) which considers the ratio of input to output in organisations. More recently, other researchers have also used different indicators to measure the performance of refineries. For example, Hosseini and Stefaniec (2019) used a two-stage slacks-based framework to evaluate the efficiency of Iranian oil refineries using operational and profitability subunits. Badmus et al. (2012) applied exergy analysis technique to analyse the fuel-mix and energy utilisation patterns in Port Harcourt refinery as a means of determining their operational efficiency. This study adopted the concept of capacity utilisation as a performance measure for the NNPC refineries. Capacity utilisation is the ratio of the actual production of the refineries to their installed capacity. With a total installed capacity of 445,000 bpd, the capacity utilisation of the NNPC refineries from 2001 to 2019 is plotted as shown in Figure 4.

>>>Insert Fig 4<<<

Figure 4 indicates that the overall capacity of the refineries has steadily declined for the past 19 years to be currently below 20%. Iheukwumere et al. (2020) compared the capacity utilisations of NNPC refineries with refineries from countries with similar economies to Nigeria over a five-year period. This comparison is as shown in Figure 5 and reveals that the capacity utilisation of NNPC refineries fall far below the operating standards for the refineries in Angola, Egypt, and South Africa.

>>>Insert Figure 5<<<

The values for Figure 5 stopped at the year 2018 as all the NNPC refineries have mostly been under a shutdown for turnaround maintenance assessment since late 2019 (Reuters, 2020).

Having established the low-capacity utilisation across the NNPC refineries, this study adopted the concept of systems thinking to examine the interrelationships amongst the causal PEST factors. This is done with a view of identifying the leverage points within the causal loop model where policy changes can improve performance (Videira et al., 2014). Arnold and Wade (2015), Meadows (2008) and Goodman (1997) opine that a problem requires adoption of a systems thinking approach when the issue is significant, chronic, complex, has a known history and has evaded previous attempts for a solution. The problems affecting the productivity of the NNPC refineries appear to match these descriptions.

4.0 Systems thinking

The fundamental concepts of systems thinking developed within the 20th century as a field of inquiry and practice covering several disciplines such as biology (Bertalanffy, 1968), anthropology (Ashby, 1956; and Bateson, 1972), mathematics (Weiner, 1948), computer science (Forrester, 1968). and management (Checkland, 1981; Senge 1990; and Ackoff, 2003). Systems thinking is a holistic approach to the analysis of complex problems with multiple interrelationships within its constituent parts which generate a behaviour over time (Cabrera &

Cabrera, 2015; Mingers and Leroy, 2010; Monat and Gannon, 2015). According to the Association of Project Managemen (APM) (2018), systems thinking may be described as a discipline for seeing wholes rather than parts, for observing patterns of change rather than static snapshots, and for understanding the subtle interconnectedness that give systems their unique character. Systems thinking promotes the understanding that the world is made up of interconnected and hierarchical social and technical entities, which are organised to produce unique behaviours that are not often likely to be predicted from observing the parts of the systems in isolation (Senge, 2006 and Sherwood, 2011).

Systems thinking may be viewed as a perspective, which may be associated with organised complexity that often manifests as repeated events or patterns in organisations (Monat and Gannon, 2015; Weinberg, 2001 and Senge, 2006). This makes systems thinking useful for the understanding and analysis of complex business and socio-economic problems - in which context, a system has been defined as a group of interdependent parts (elements) that form a unified complex whole with a specific purpose (Senge, 2006; Sherwood, 2011; and Meadows, 2008). As such, an organisation may be regarded as a system with its workers as the elements. The organisational components can be interconnected by employee cooperation and organisational policies and procedures with a purpose to grow and serve the community.

The problems of the Nigerian petroleum refining industry can be analysed as a system comprising several sub-category PEST factors acting together over time to generate operational inefficiency. It is important to note that the factors which drive the performance of the refineries act both internally (endogenous variables) and externally (exogenous variables). The differences in the operationalisation of these factors are presented in Section 5.0 (methodology).

4.1 Causal Loop Diagrams (CLDs).

Causal Loop Diagrams (CLDs) are systems thinking tools used to communicate interrelationships between variables in a system (Videira et al., 2014 and Sterman, 2010). CLDs show interconnecting variables (factors) in a system in particular directions using positive or negative notations accordingly. For example, a CLD in which an increase in variable A produces an increase in B is represented by a curly arrow bearing a positive sign (+) from A to B, while a CLD for a variable B producing a decrease in variable C is represented by an arrow bearing a negative sign (-) from B to C.

Meadows (2008) identified two kinds of loops in causal loop diagrams – a reinforcing loop and a balancing loop.

4.1.1 Reinforcing and Balancing Loops

A reinforcing loop or positive feedback loop is one in which an action produces a change which furthers more of the same action and thus leads to a further increase or decrease in a specific property of the system (Sherwood, 2011 and Gharajedaghi, 2011). These loops tend to destabilise systems due to their snowballing effect, i.e., small changes to the system tend to produce larger changes in an ever-growing manner (Sherwood, 2011). Reinforcing loops can produce growth or decay in a system depending on the variables they act upon. They are characterised by all positive signs in a loop. They can also be indicated by a loop with a combination of positive signs and an even number of negative signs (Sterman, 2010 and Haraldsson, 2004).

Conversely, a balancing loop is one in which a counteracting force acts to resist the growth or decline of a system and thereby tends to restore its balance. In notations, a balancing loop is characterised by an odd number of negative signs, which may be acting alongside some positive signs in a loop to force a braking effect on the growth (or decline) of the system (Haraldsson, 2004). Balancing loops are goal-seeking in nature, i.e., they tend to move things from the current state (by closing a gap) to a desired state.

Sterman (2010) opines that while drawing causal loop diagrams, it is imperative to use the significant variables acting upon the system in order to keep the model simple. However, the use of only significant variables may not be adequate to fully explain the behaviour of a system. As such, other variables (fuzzy variables) which help explain the operationalisation of the system are usually incorporated in the diagram (Sherwood, 2011). The overall goal of developing a causal loop diagram is to understand the general behaviour of the system to identify the leverage points where policy changes can be applied to correct the behaviour of the system.

5.0 Methodology

As earlier indicated, this study was designed to use the significant factors affecting the NNPC refineries to develop a causal loop model that will guide policy recommendations to improve performance. Figure 6 is a schematic representation of the research approach.

>>>Insert Figure 6<<<

Figure 6 indicates the sequence of data collection from literature review to model development.

5.1 Research Instrument and Data Collection

A mixed methods approach was adopted by the study in a sequential manner to collect both quantitative data via a Likert-type questionnaire and qualitative data via semi-structured interviews. The interviews were conducted to further explore the findings of the questionnaire. The significant variables obtained by both methods of enquiry were then used to develop the causal loop model.

5.1.1 Questionnaires

The questionnaire study was conducted using a purposive sampling approach to ensure only relevant experts with better understanding of the refinery issues were targeted (Bryman, 2016). The questionnaires were also pilot tested with 25 staff members polled from the various NNPC refineries and improved before the final development.

Using a five-point Likert-type questionnaire, the study was designed to obtain the professionals' view on the most significant PEST factors that impact on the performance of the refineries. Jamieson (2004) and Kaptein et al., (2010) agree that Likert-type scales have been proven useful for evaluating interactive experiences of respondents to obtain quantified data regarding their attitudes, behaviours, and judgements.

The data for the questionnaire were derived from published academic literature on factors that limit the performance of refineries.

The survey was deployed via an online tool – google forms and targeted about 200 professionals who work across the refineries. A total of 118 respondents completed the questionnaires. The experience of the respondents ranged from 3 years to 10+ years indicating some good grasp of knowledge about how things work in the organisation. Most of the respondents have an engineering background with 54% of them having at least a BSc or Higher National Diploma (HND) and the other 46% with a master's degree. About 6% of all respondents occupy middle to senior management positions in the organisations. Table 3 show the demographics of the research participants.

>>>Insert Table 3<<<

Respondents were first asked how they would rank the impact of the stated Political (P), Economic (E), Social (S), and Technical (T) factors on the performance of the refineries with options ranging from *Least Impact* representing 1 to *Highest Impact* representing 5 on the Likert scale.

5.1.2 Interviews

On the other hand, the semi-structured interviews were carried out with 11 members of senior staff of the refineries and 3 members of senior staff from other NNPC units (downstream and corporate services) for validity and reliability purposes. The interview was carried out to further explore the meanings of some of the questionnaire responses.

The three senior staff members from other NNPC units were individuals who occupy senior management roles with at least 15 years' combined experience each while working at different subsidiaries of the organisation. Whereas the 11 members of senior staff of the refineries comprise the staff members of the refineries with at least 10 years of experience working for any of the NNPC refineries. Table 4 show the demographics of the interview participants.

>>>Insert Table 4<<<

The identified factors from the interviews were used as additional input variables to refine and enhance the understanding of the factors from the questionnaires. These variables were then used to construct a systems-based causal loop model to show the interrelationships of the factors and how they jointly operate to drive operational inefficiency across the organisation. Lastly, the model was validated by expert interviews from some staff of the refineries and recommendations were made based on this model on how policy changes can be effectively applied to overcome the identified challenges.

6.0 Results

The results of the questionnaires were analysed by structural equation modelling (SEM) while the interviews were analysed by content analysis.

6.1 Questionnaire Analysis

This section explains the rationale for choosing structured equation modelling as a statistical analysis tool for the PEST factors. Structural Equation Modelling (SEM) is an advanced form of statistical analysis that utilises mathematical models and computer algorithms to explain complex relationships of data constructs in graphical networks (Raykov and Marcoulides, 2012; Kaplan, 2008; and Martynova et al., 2018). Kline (2011) notes that SEM comprises path analysis, confirmatory factor analysis, confirmatory composite analysis, latent growth modelling as well as partial least square path modelling. Particularly, SEM is an extension of path analysis and is based on the same mathematical concept belonging to the family of general linear models (GLM) (Klein, 2016; Streiner, 2006). The use of SEM has been proven useful in social and management sciences for its ability to utilise the concept of observed and latent variables to input structural relationships between multiple factors which represent direct and indirect constructs (Martynova et al., 2018). For example, since human intelligence cannot be quantitatively measured directly, SEM can be adopted for such measurement to treat intelligence as a latent variable and other measures through which intelligence can be assessed as the observed variables. Salkind (2007) reports that psychiatrists used various questions to measure the academic performance, which reflects students' intelligence, using their standardized test scores in SAT, ACT and High School CGPA as the observed variables, while regarding intelligence and academic performance as the latent variables. Figure 7 represents the structural equation model path diagram for this concept.

>>>Insert Figure 7<<<

Figure 7 shows that the observed variables are drawn in squares while the latent variables are drawn in circles. In that context, SEM can be adopted to measure the Political, Economic, Social and Technical (PEST) factors in this study as the latent variables while the subfactors measured via the Likert-type questionnaire would represent the observed variables. The interrelationships between the observed and latent variables were observed to elucidate the cogent variables for the purpose of developing the causal loop diagram in this study.

Weston and Gore (2006) outlined six steps for formulating SEM, and they include: model specification, identification, data preparation and screening, estimation, evaluation of fit, and modification. Adopting these steps, the questionnaires were analysed, and the structural equation was developed as indicated in Table 5.

>>>Insert Table 5<<<

Nine (9) equations were developed to represent the relationships between the variables using the symbol "~". The p value of the Chi-square test (Table 6) indicates the asymptotic significance of the model. Hence, if $P< 0.050$, the model is significant. In this analysis, p is 0.001 which is <0.050.

>>>Insert Table 6<<<

The Chi-square (χ^2) value of 868.096 and the Chi-square statistic of the minimum function test value of 3.807 proved the model fitness. The value of 868.096 is a very large Chi-square value which indicates greater association between the variables in the model. The degree of freedom for the test of model fitness can be derived by deducting the observations which were used in the estimation which shows the total number of observations has a value of 225. The value of 225 indicates a large degree of freedom and fitness of the model for the analysis.

>>>Insert Table 7<<<

The parameter estimates in Table 7 displays the asymptotic significance values which should be less than 0.050. Almost all the relationships have p values < or equal to 0.050. The Z values show how the relationships' standard deviations are away from the mean. If the Z value is equal to 0, then the score is the same as the mean. Higher or lower Z values indicate the standard deviations are higher or lower than the mean. In Table 8, the Z values are very far away from the mean values which is centred at 0. More importantly, the standard deviation (std) values are used to determine the direction of individual relationships. All std values from 0.70 and above in Table 7, were deemed important in understanding the strength of the relationships. Overall estimated std. relationships that fall between 0.70 and 1.00 portray strong, 0.4-0.6 are medium and 0.00 to 0.30 are weak relationships (Rosseel, 2012). Figure 8 shows the strengths of the relationships with the thicker green lines representing stronger relationships. The thinner green lines which represent weaker relationships were not considered in the variable selection.

>>>Insert Figure 8<<<

Figure 8 further identified, a strong relationship between JC_.3, Technical factors and JC_.1, Economic factors with looping values of 0.76 and maximum 1.00. Thus, proving that technical factors pertaining to refinery maintenance are strongly influenced by economic factors such as cost of spare parts and operating capital. This implies that economic conditions in Nigeria may influence the release of maintenance funds to keep the refineries running. JC_.2, Social factors has a strong std value of 0.900 and will form a major part of the causal loop diagram. The analysis proved that social factors are very important in Nigeria's refinery management.

>>>Insert Table 8<<<

Table 8 provides a breakdown of drivers selected from the path diagram (Figure 8), for the purpose of creating the causal loop diagram. For instance, JC_.0 showing the political factors identified government interference (0.84); political indecision (0.78); funding issues (0.69) and managerial appointments (which has an internal strength of 0.93 from the path diagram) as the main variables under the political factors. Individually, JC_.2, the social factors identified collusion and sabotage as the main social driver with a value of 0.73. Economic factor, which is JC_.1 in the path diagram related more with cost of spare parts (0.82); operating capital (0.92); and subsidy issues (0.81) as the prime economic drivers. Finally, JC_.3, technical factors related more with maintenance issues (0.76); Ageing refineries (0.76); limited plant capacity (0.84); and feedstock supply (0.79). All drivers with approximate relationships from 0.70 and above indicate strong relationships exogenously and endogenously and hence, were documented in Table 8 for the purposes of the causal loop model development.

6.2 Interview Analysis

The interviews were analysed using content analysis to follow up on the results from the questionnaire analysis. A detailed review of the interview transcripts revealed relevant patterns to the research purpose, which were coded using NVivo 10 to categorise the emerging themes from the text data. The NVivo 10 software helped to establish relationships associated with sentences coded into nodes, thereby enhancing the understanding of causality of the variables at play within the refining sector. The process for this analysis followed the steps recommended by Schmidt and Hunter (2015) as follows:

1. Material categorisation to identify different aspects of the investigation.
2. Categorisation of the themes according to the research questions and objectives
3. Breaking down of sentence structures into codes relevant to research questions and objectives
4. Linking coded information together to build cases, and
5. Interpreting the cases to provide meaning and context to the research.

After establishing a set of categories based on intercoder agreement, four new variables emerged while analysing the transcripts with NVivo 10. These variables, which were justified by comparing the interviewer comments alongside existing literature include the following:

1. Intervention time
2. Facility reliability
3. Management autonomy
4. Maintenance issues (reactive approach)

6.2.1 Intervention time

When asked how government interference (which was a high-ranking variable from the questionnaire) affects the refinery performance, INT-3, INT-5 and INT-9 echoed similar comments. According to INT-3, "…when government fails to release needed funds in time, it delays the time the refineries will need to get the problems resolved" this implies that such delays prolong the time for the refinery equipment to get the attention it requires. INT-5 also stated, "[….] since I started working here, I have never witnessed a time when an equipment would breakdown or was about to breakdown and an appeal is made for funds to quickly resolve the issue and get approved in time". This situation appears to exacerbate issues at the refineries and consequently lead to increased downtime from equipment breakdown. INT-9 also observed "…. if the boss of each refinery had the full authority to access adequate funds, they would be more likely to intervene and respond to issues quicker and the refineries would be working better today". These assertions also highlight the importance of funding for the refineries as well as autonomy. This is consistent with the assertions of Ogbuigwe (2018) that since the refineries lost their governing autonomy, they now depend on politicians to get funding for their maintenance. Clearly, this structure unnecessarily prolongs intervention times for the refineries with multiple consequences that culminates into equipment breakdown.

6.2.2 Equipment reliability

The reliability of the refinery equipment is a major issue of concern. Most of the interviewees agreed that the continuous repair of some equipment parts even in cases where they ought to be replaced reduces their reliability. This is an effect of limited funding to procure the required equipment parts for replacement. INT-7 emphatically stated: "[…] if there are adequate funds, some of the equipment parts we repair would have been replaced with new ones". INT-5 also stated: "[…] some of these equipment are overworking themselves and are long overdue for replacement". These views are consistent with the assertions of Igboanugo et al. (2016) and Mamudu et al. (2019) that poor equipment reliability of the NNPC refineries is a major contributor to their breakdown.

6.2.3 Lack of refinery management autonomy

The inability of the Managing Directors (MDs) of the NNPC refineries to independently approve funds for the maintenance of their facilities significantly delay intervention time and cause maintenance issues to escalate. INT-11, INT-2 and INT-9 specifically echoed these sentiments when asked to explain how the refineries approve maintenance jobs. For example, INT-2 stated: "[…] the refinery MDs do not have the capacity to release funds for any major maintenance operations of their plants. Such approval must be issued from the presidency via the NNPC Group".

6.2.4 Maintenance issues (reactive approach)

When asked to explain how maintenance issues cause problems at the refineries. All the interviewees agreed that there was no planned approach towards maintenance at the refineries. Instead, the refineries' approach towards maintenance has been reactive rather than proactive. INT-6 stated: "[…] although we have various maintenance schemes at the refineries such as preventive, corrective, and turnaround maintenance…these programs are not being implemented as they should… it is usually when things break down that we go and check what has happened…sometimes it would be a minor thing that we need to fix, other times, it would be a major thing we can't fix by ourselves […]". Also, when asked why it takes time to fix some of the broken equipment, INT-10 stated: "[…] the truth is that our engineers do not have the wherewithal to surmount some challenges…you know there is no structured approach to staff training here. If we are well trained, maybe we can do a lot of the jobs by ourselves and save time and cost. Some of the trainings we receive are actually irrelevant to our operations as management can suddenly decide to send some people on any training they think of regardless of the usefulness of the training to our operations. […]".

7.0 Analysis and model development

Sherwood (2011) suggests that developing a causal loop model from only the significant questionnaire variables would yield a poor and incomplete model. Therefore, other methods for data collection such as interviews were employed to seek the operational meanings of some of the variables as well as to enhance the understanding of how they interlink with each other. Sterman (2010) agrees with this notion by suggesting that a more reliable model cannot be developed without the input of the practitioners who experience the issue in question. Such inputs were reported to include the use of focus group discussions, interviews, or direct observations (Boateng et al., 2015).

Using the variables which emerged from the interview analysis alongside those from the SEM analysis of the questionnaire, two forms of variables can be distinguished as shown in Figure 9.

>>>Insert Figure 9<<<

Endogenous variables are the factors which internally influence the system operationally, while exogenous variables are the factors which bear external influence on the operationalisation of the refineries. Table 9 provides the full list of these factors.

>>>Insert Table 9<<<

Taking this phenomenon into consideration, the causal loop model was developed using two different colours to distinguish these variables (endogenous – black; and exogenous – light blue) while showing the overall interrelationships amongst the factors acting on the Nigerian refining system (Figure 10).

>>>Insert Figure 10<<<

7.1 Analysis of initial model

The model shown in Figure 10 is a general representation of the interrelationships of the causal factors leading to the decay and sub-optimal performance across the NNPC refineries (PHRC, WRPC, and KRPC). The use of a single model to represent the conditions at the three NNPC refineries is justified as the refineries share the same management and operational structure (Gharajedaghi, 2011 and Sterman, 2010). For example, crude oil (feedstock) is sent to all the refineries from the Pipelines and Products Marketing Company – PPMC (a subsidiary of NNPC) and the refined petroleum products from the refineries are also returned to PPMC for sale and distribution to marketers (Akinola, 2018). Similarly, none of the NNPC refineries have an independent authority to carry out any major maintenance operations and most major maintenance operations are usually decided at the parent NNPC Group with the approval of the federal government.

To read and interpret the model, it is pertinent to note the meanings of some variables as used. Variables with "issues" appended to their names generally refer to problem variables. For example, *maintenance issues, funding issues*, and others as used in the model can be interpreted as *maintenance problems* and *funding problems.* However, following the interviews, some variable names like maintenance issues, as represented in the questionnaire were broken down into *accumulated maintenance issues*, *turnaround maintenance* and *corrective maintenance* in order to better capture their operational meanings.

Generally, the model in Figure 10 reveals three problem clusters which could provide leverage for policy change in the system. These clusters are accumulated maintenance issues, which leads to ageing refinery plants and equipment breakdowns; government interference, which withholds the autonomy of the refineries to independently manage their affairs; and pipeline attacks, which appear to derive from collusion and sabotage, illegal refining activities, and security issues.

The two loops in the model (B1 and B2) show that a lack of regular maintenance in the entire system allows accumulated maintenance issues to build up leading to plant breakdown. Over time, the breakdown of the refinery equipment results in either a corrective maintenance or a turnaround maintenance. The corrective or turnaround maintenance, when carried out eliminates the accumulated maintenance issues, fixing the refinery plants and eventually increases the production capacity. It should be noted that the maintenance culture in this organisation is primarily reactive, hence the two balancing loops B1 and B2 continue to attempt to return the system to a broken state.

Another important cluster in the CLD is the government interference. This variable obviously reduces the management autonomy at the refineries and increases funding issues through approval delays. This also leads to an increase in the intervention time for the refineries. The overarching effect of these links is the persistent breakdown of the refineries and their reduced capacity utilisation.

The cluster surrounding pipeline attacks in the model is obviously fuelled by the activities of vandals seeking to steal products for illegal refining. Weaknesses in the securing systems around pipeline infrastructure as well as collusion and sabotage by actors within the communities also contribute to this behaviour (Akinola, 2028 and Ogbuigwe, 2018). The resultant effect of these interactions is the reduction of feedstock supply to or from the refineries.

These clusters, however, present significant leverage points for policy intervention in the system for production optimisation.

7.2 Proposed model and validation

To achieve an improved performance across the refineries, a proposed model is developed and validated by the experts (interview participants) to correct the anomalies and performance gaps in the previous model. This validation was done by breaking the model into segments and sending these across to the participants via email with a guide as to how the diagrams are drawn. This was done with a view to obtain their input and consensus on how the factors are operationalised in the refineries. Finally, the overall model was redrawn to accommodate the remarkable links from the various participants.

The leverage points presented by the clusters in the previous model (Figure 10), reveals opportunities to exploit the advantages offered by these linkages. Figure 11 is a corrected causal loop diagram, which fixes the inefficiencies of the previous model.

>>>Insert Figure 11<<<

8.0 Discussion and analysis of proposed model

It can be observed from Figure 11 that a major shift in maintenance approach to incorporate the various aspects of routine, corrective, and turnaround maintenance as required would eliminate accumulated maintenance issues and unnecessary plant breakdowns. In addition, it can be observed that establishing a management autonomy for the refineries would afford the organisation the control to forge necessary partnerships that would help it implement proper staff training and re-orientation. This would in turn contribute towards best practice by reinforcing the continuity of the various maintenance programmes. The social issues surrounding pipeline attacks, illegal refining, security issues as well as collusion and sabotage, necessitates a stronger need to satisfy the stakeholders. This can be achieved through effective community engagement targeted at building quality and trusted relationships between the organisation and the host communities. Figure 12 is a schematic of the three proposed policy levers that can turn around the performance standards of the refineries.

>>>Insert Figure 12<<<

Figure 12 implies that management autonomy, best practice, and stakeholder satisfaction can effectively replace government interference, maintenance issues and social issues, respectively.

Government interference can be effectively replaced by granting the refineries autonomy or privatising the entity to guarantee them full independence in the management of their affairs. To this end, it would be essential for the NNPC to divest itself of the refineries and allow these subsidiaries to become private sector led. This can be achieved either by the NNPC relinquishing their controlling stake to a private sector with better expertise and financial power to transform the refinery to global standards. However, researchers suggest that this objective can only be realised in a fully deregulated downstream environment, where investors can freely operate the refineries under prevailing market rates (Iheukwumere et al., 2021). To ensure transparency in this arrangement, government can fairly monitor the industry via the Department of Petroleum Resources (DPR) to protect the interest of the consumers.

Best practice is proposed to address maintenance issues in the model and refers to the standard maintenance practice of operating refineries. Azadeh and Zadeh (2016) identifies preventive (proactive) and reactive (unplanned) maintenance approaches as commonly adopted across the industry. This is consistent with the opinions of some of the interviewees that there is no planned approach towards maintenance in any of the refineries.

This implies a general lack of coordinated approach towards maintenance across the refineries. It also evidences the reactive nature of maintenance programs within the NNPC refineries, which has been proven to be more costly considering the associated unproductive downtime it incurs (Azadeh and Zadeh, 2016; Eti et al., 2006; and Duffuaa and Ben-Daya 2004). A policy shift towards a proactive maintenance approach would be essential to address this gap.

Stakeholders satisfaction is proposed to discourage social issues regarding sabotage, grievances and to an extent, illegal refining activities that lead to increased pipeline attacks. It is important to note that aside from the government (owners) and the public served, the host communities of the refineries are the main stakeholders that must be satisfied to address these social issues. The model shows that community engagement and empowerment would help actualise this objective. This view is in line with the assertions of Osobajo and Moore (2017) that organisations (businesses) can satisfy their community stakeholders through quality relationships that promote empowerment and greater sense of belonging for the members of the community. However, Moffat and Zhang (2014) suggest that building such relationships might take some time to actualise. Notwithstanding, such relationships would be essential to reduce the incidence of violent attacks by the youths on the refinery infrastructure. Additional examples of how NNPC can meaningfully engage their communities include targeted employment and developmental opportunities to improve the average quality of life of its people. This can be enhanced through increased corporate social responsibilities (CSR) to provide electricity, water supplies, free healthcare facilities, schools, bridges, markets, good roads as well as scholarship opportunities for the teeming youths in the operational areas (Ijaiya, 2014). Although the NNPC has a CSR programme in place covering some of these activities, additional efforts should be made by the corporation in partnership with the government to explore multiple paths to determine and address the root cause of aggression of the Niger Delta youths who target and vandalize crude oil pipelines.

To address the problem of illegal refining, which is a major contributor to pipeline vandalism, Umokoro (2018) proposed the legalisation of illegal refineries in the Niger Delta as a pathway to recognise, support and train the local artisans towards increasing the capacity of locally refined petroleum products in the country. Unfortunately, given the level of technology required to adequately process crude oil, it is unlikely that a mere legalisation of this practice would be sufficient to standardise the operations of these rudimentary refineries. A better approach should involve the partnership of the federal government with technical experts alongside the community stakeholders to create a special purpose vehicle (SPV) for building additional small-scale refineries to maximise RPP production in the country.

9.0 Conclusion

This study was carried out to build a causal loop model showing the interrelationships of the significant factors which drive the operational inefficiency across Nigeria's state-owned refineries. Using a framework of political, economic, social, and technical (PEST) factors, the causal loop model of these factors were explored for leverage points upon which policy changes may improve performance in the system.

The study identified three main cluster points which provided critical leverage points for policy intervention. Consequently, the implementation of best practice to incorporate the various aspects of proactive maintenance programmes to address equipment failures in the refineries were recommended. The establishment of autonomy for the governance of the refineries was proposed to encourage partnerships that will infuse the necessary financial and technical re-orientation to drive best practice across the refineries.

Lastly the effective engagement of stakeholders within the operating communities through quality relationships that incorporate sincere efforts to address the root cause of aggression of disgruntled youths who break into oil pipelines is recommended. In addition, the implementation of robust asset management system that assures a routine inspection of the pipelines for quick detection of rupture or compromise would be required to reduce loss times due to breakdown and help save cost.

This study shows that systems thinking can be very helpful in understanding the complexity of the interconnecting factors which act together to produce growth or decay in organisations. The causal loop model developed through this study uncovered key leverage points for policy intervention to improve the performance and productivity of the refineries. The implication for policymakers is to recognise the impact of the systemic behaviour of the multiple PEST factors while seeking to resolve the challenges of the refineries.

10.0 Limitations of the study

The causal loop model as presented in this study only explored the interrelationships amongst the significant factors that affect the performance of NNPC refineries. The study did not investigate the dynamic interactions of the variables which act on the system. A future study can be carried out to simulate the dynamic interactions and sensitivity analyses of changes in these variables to determine their impact on the system behaviour. However, this is beyond the scope of the present study.

Conflict of interest

The authors declare no conflict of interest for this paper.

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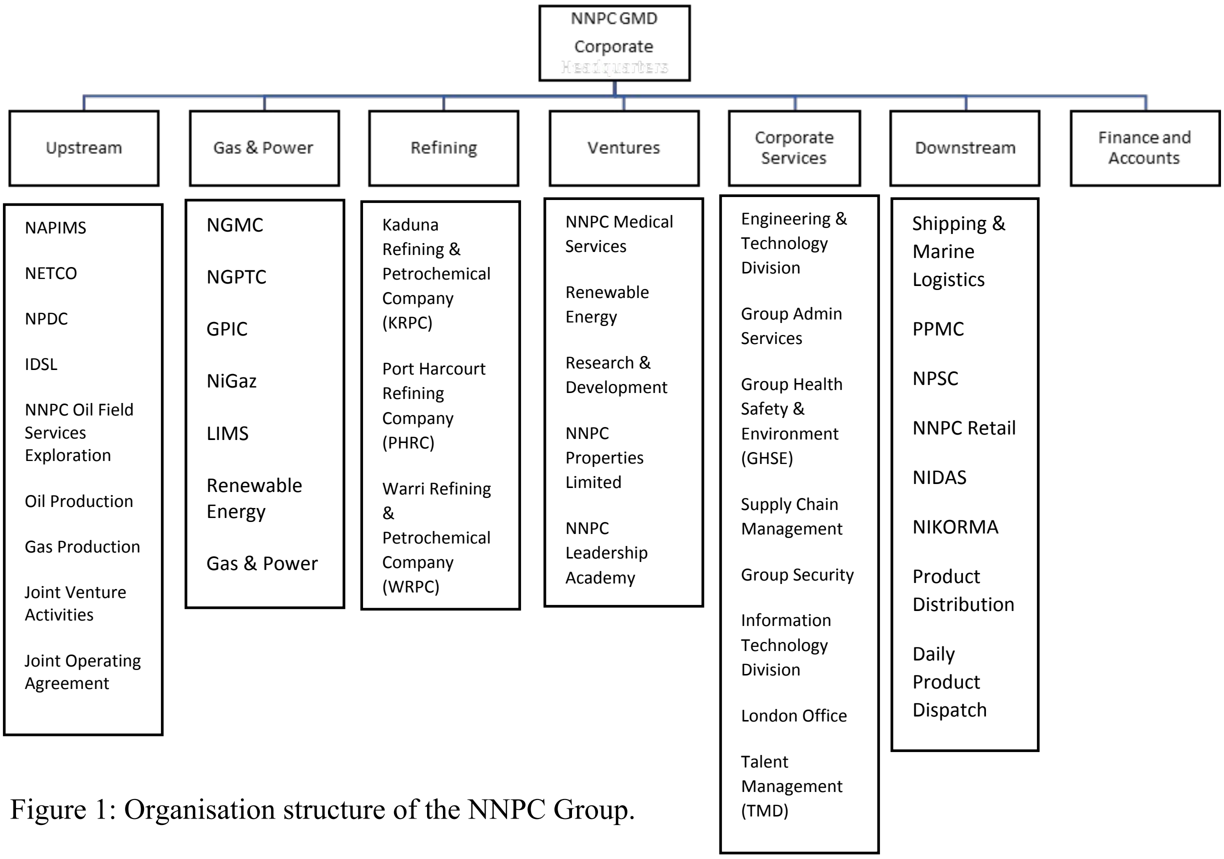

Figure 1: Organisation structure of the NNPC Group.

Source: Author generated, adapted from NNPC website, NNPC (2020).

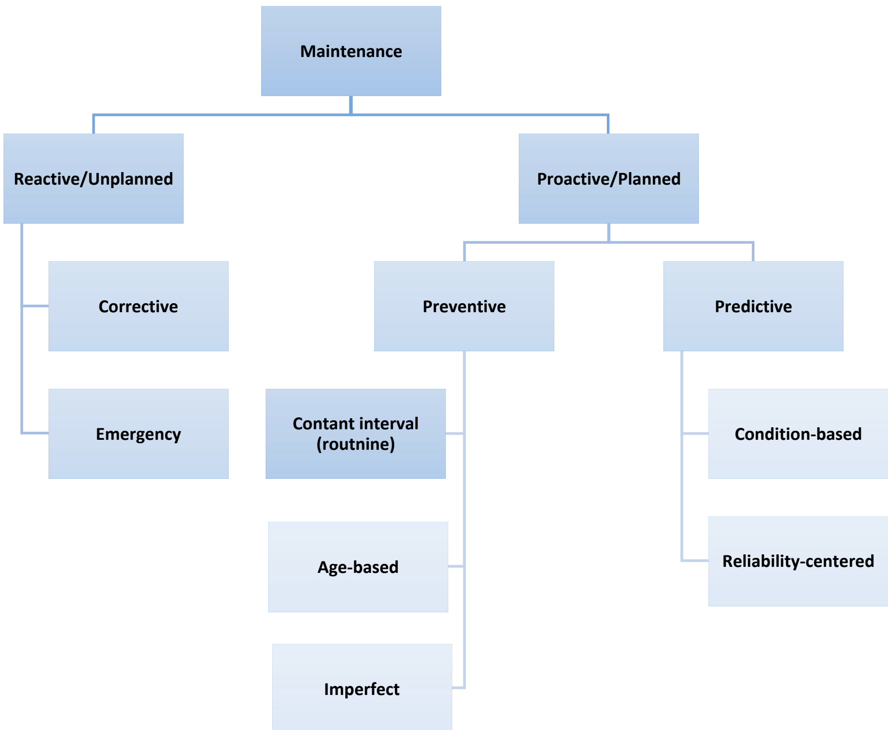

Figure 2: Overview of various maintenance categories

Source: Adapted from Azadeh and Zadeh (2016).

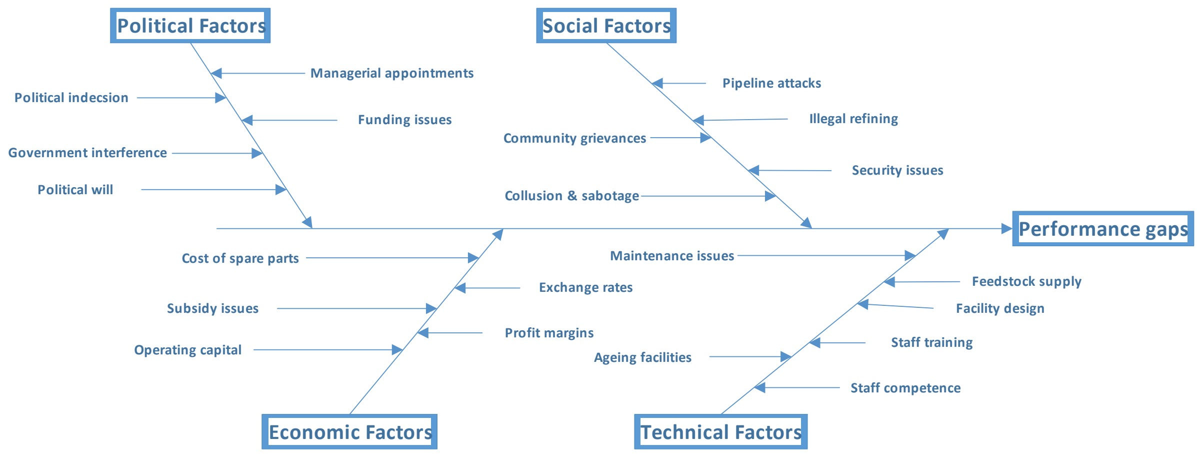

Figure 3. A cause-and-effect diagram of the sub-PEST factors affecting NNPC refineries.

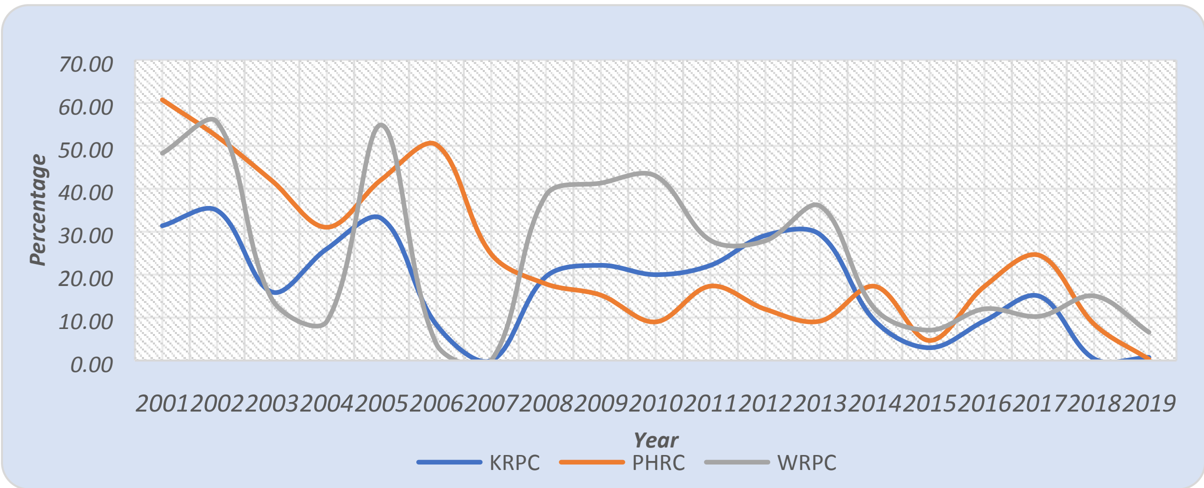

Figure 4: Capacity Utilisation of NNPC refineries (2001 - 2019)

Source: NNPC ASB, 2001 – 2019

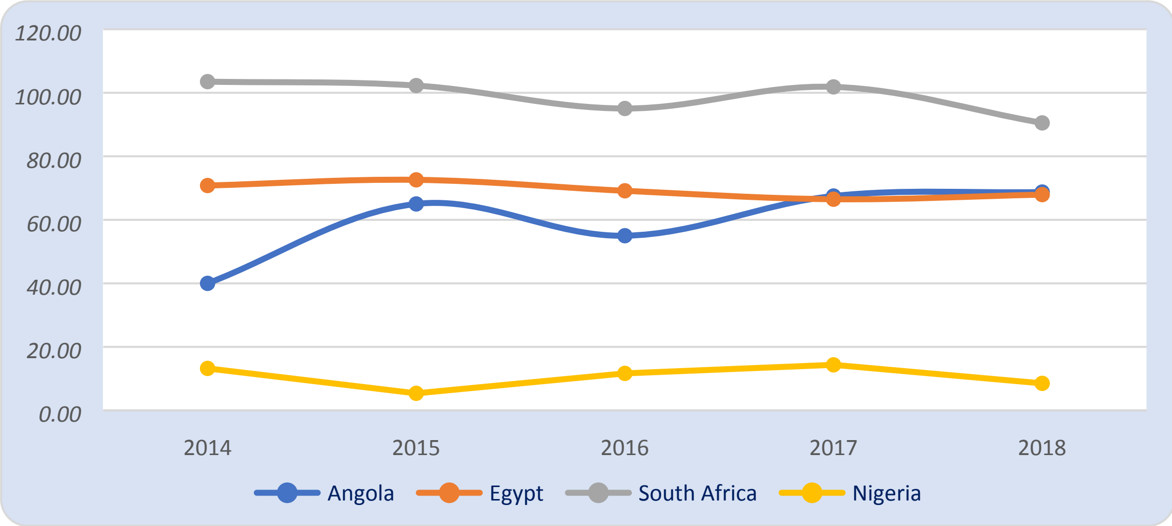

Figure 5: Refinery capacity utilisations of top African economies

Adapted from Iheukwumere et al. (2020).

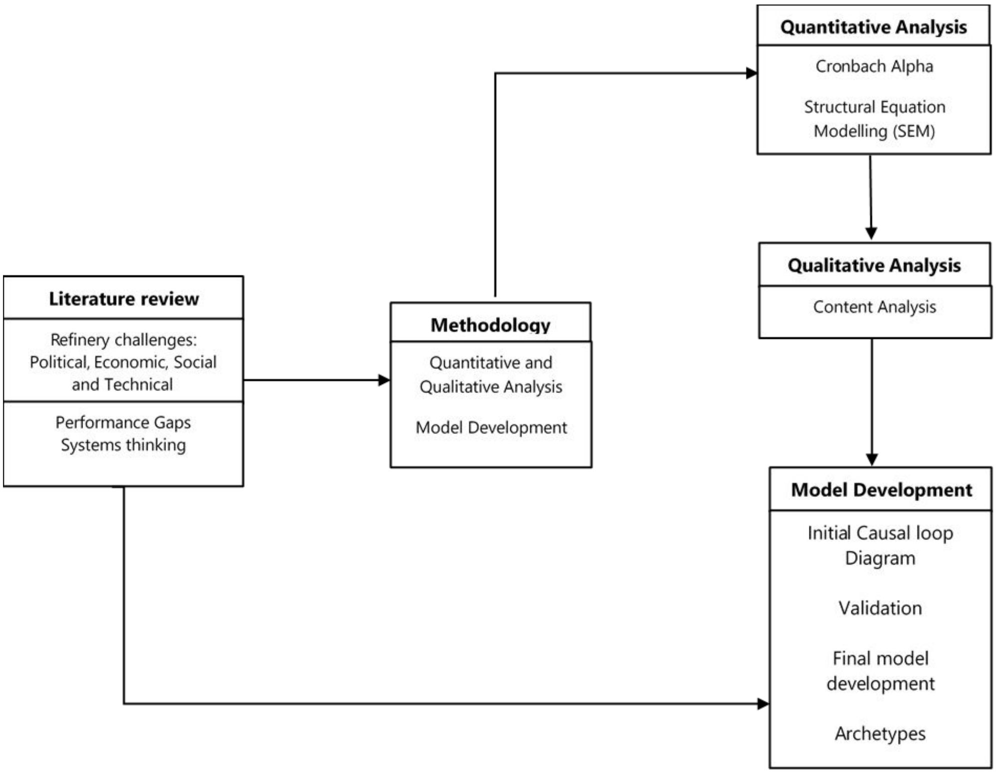

Figure 6: A schematic representation of the research framework

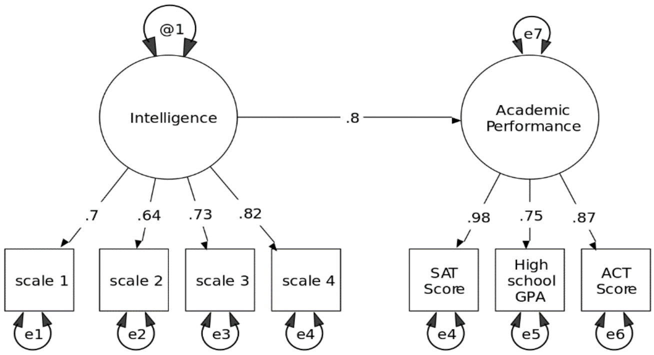

Figure 7: *Structural equation model for the intelligence test adapted from Bates (2015).*

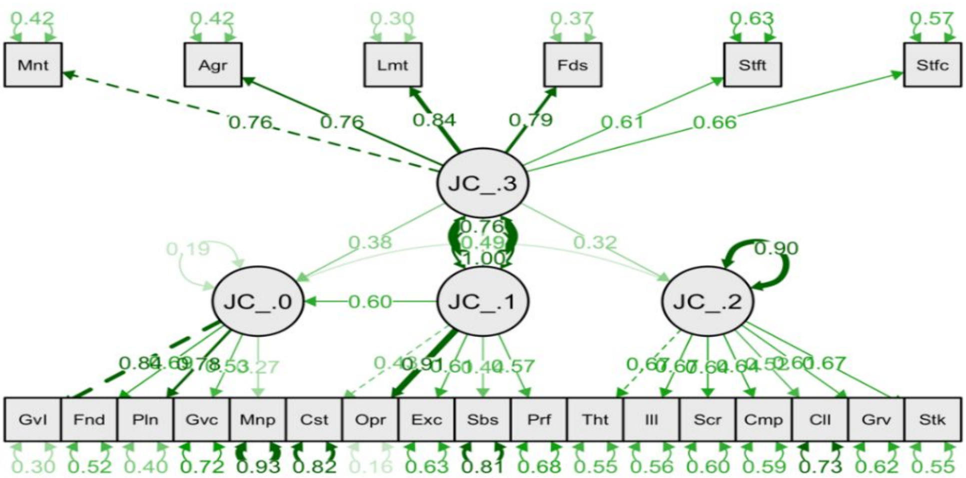

Figure 8: *Structural Equation Model for the PEST factors and subfactors.*

Notes: {Path Diagram [JC_.0= Political factors; JC_.1= Economic factors; JC_.2= Social factors; JC_.3= Technical factors;]}

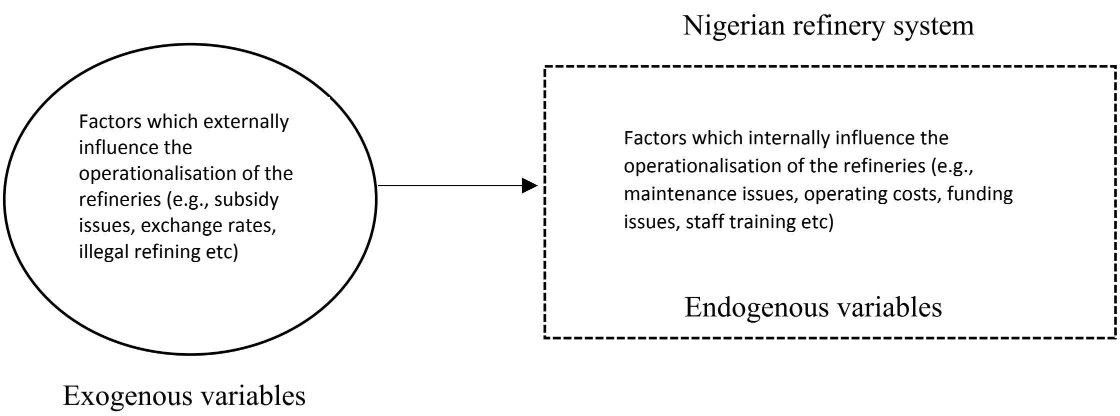

Figure 9: Schematic of the endogenous and exogenous variables acting on the Nigerian refinery system.

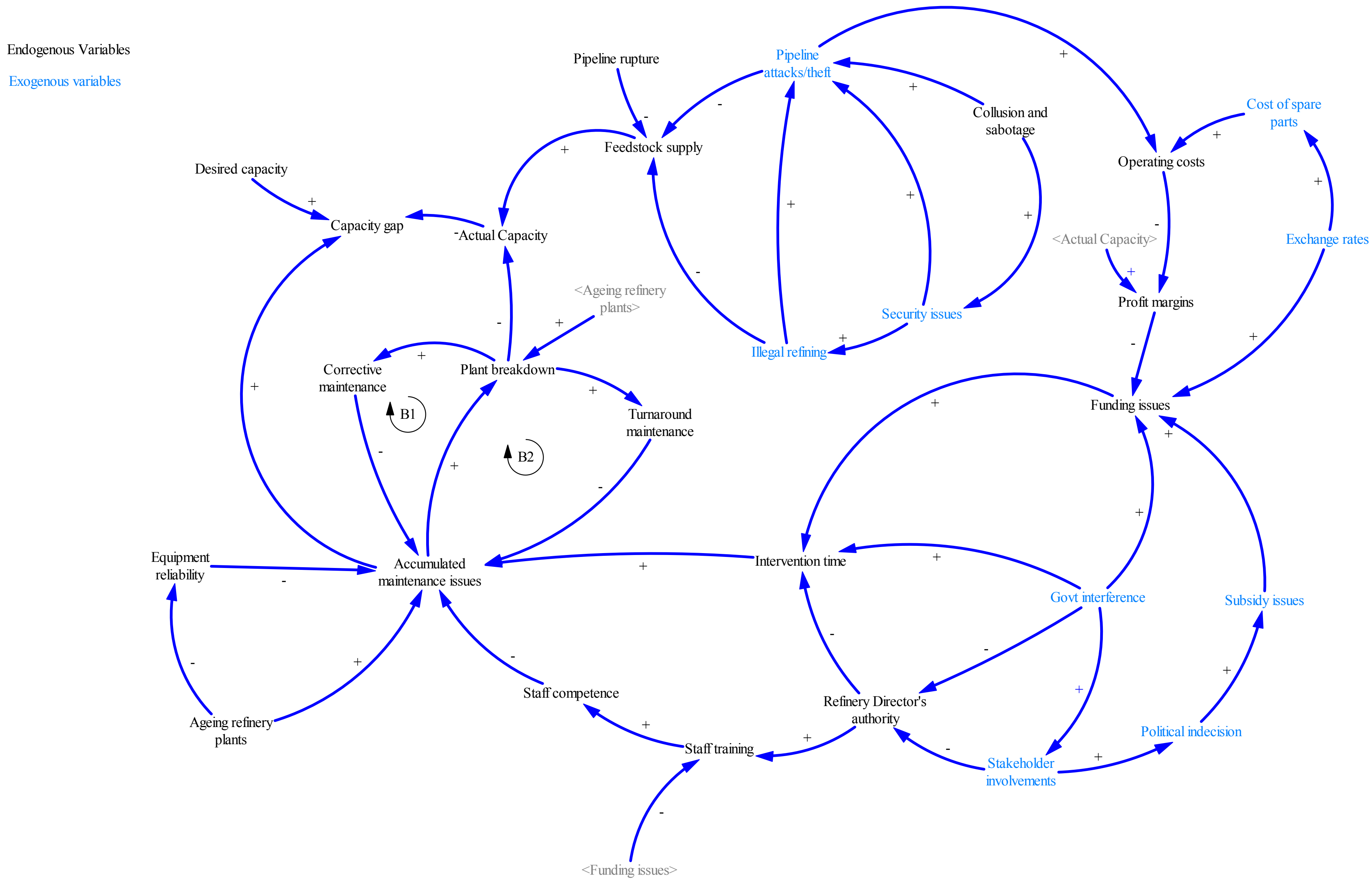

Figure 10: Initial causal loop model

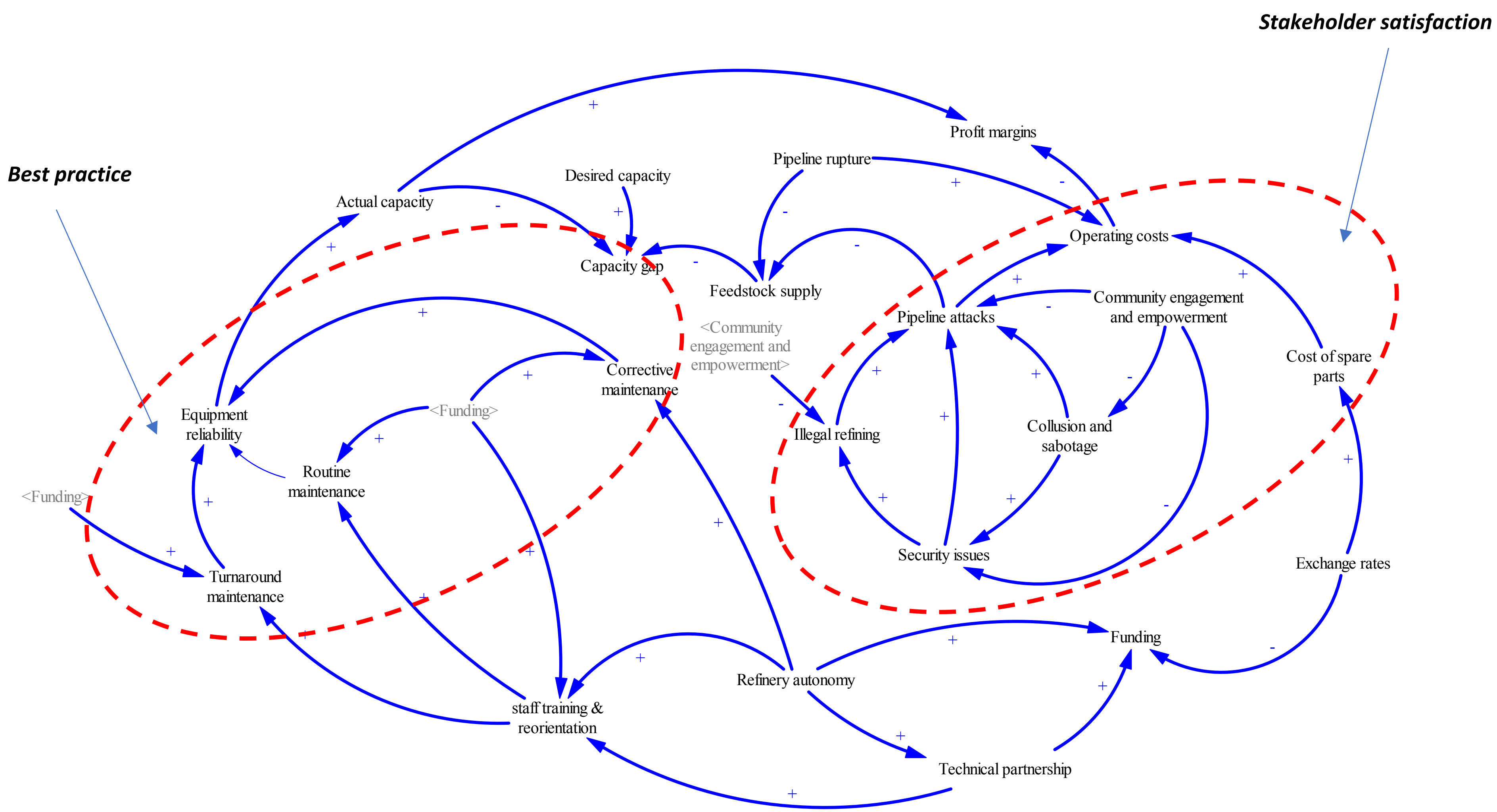

Figure 11: A proposed model for an efficient refining system.

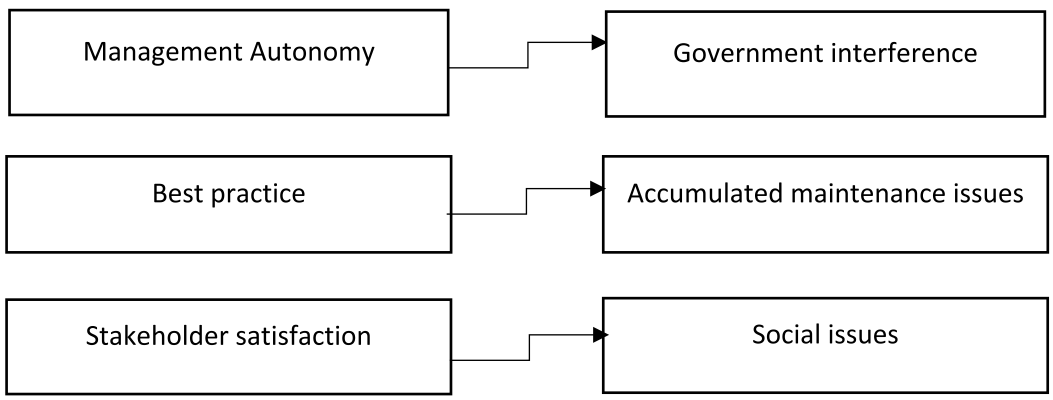

Figure 12: Policy levers for resolving the inefficiency in the refining system.

Table 1: Project details of state-owned refineries in Nigeria.

Refinery Name	Location in Nigeria	Initial Capacity	Expanded Capacity (bpsd)	Award Date	Completion Date	Construction Company	Cost of Project Award (USD)	Remarks
Port Harcourt Refining and Petrochemical Company I (PHRC I)	Port Harcourt, Rivers State	38,000	60,000 (*Expanded in 1973*)	1962	1965	Procorn Ltd, George Wimpey and Taylor Woodrow, Lloyds' Examiners & Surveyors	$39.6 M ($336M in 2021)	Built by a private consortium of Shell-BP to provide domestic supply
Warri Refining and Petrochemical Company (WRPC)	Warri, Delta State	100,000	125,000 (*Expanded in 1985*)	1975	1978	Snamproghetti	$478 M ($2.37B in 2021)	Built to increase domestic production of PMS
Kaduna Refining and Petrochemical Company (KRPC)	Kaduna, Kaduna State	100,000	110,000 (*Expanded in 1985*)	1976	1979	Chiyoda Engineering & Construction Company	$525 M ($ 2.46B, in 2021)	50,000 b/d regular fuels and 50,000 b/d lubricating fuels, waxes, and asphalts
Port Harcourt Refining and Petrochemical Company II (PHRC II)	Port Harcourt, Rivers State	150,000	Not Applicable	1985	1989	A consortium of JGC Corporation & Marubeni Corporation of Japan and Spie Batignolles of France	$850 M ($2.11B in 2021)	Built to create adequate local capacity which also paved room for export capacity which was achieved for only two years (1991 to 1993). It was short-lived due to production cuts arising from Warri and Kaduna refineries.
						Total (2021 est. val.)	**$7.276bn**	

Source: Author (adapted from literature Turner, 1977; Wapner, 2017; and NNPC, 2020).

NB: Inflation conversions done with Bank of England rates.

Table 2: PEST challenges for the NNPC refineries.

FACTORS	REFERENCES
Political Factors	
Govt interference	Ogbuigwe (2018), Akinola (2018), Wapner (2017), Sayne *et al.*(2015)
Funding issues	Chima *et al.(*2002), Ambituuni *et al.* (2004)
Political indecision	Chikwem (2016)
Government commitment/Political will	Iwayemi (2008), Adeosun and Oluleye (2017)
Managerial appointments	Onyekakeyah (2020), Sancino *et al.* (2018)
Economic Factors	
Cost of spare parts	Kennedy-Darling et al.(2008)
Subsidy issues	Akinola (2018), Iwayemi (2008), Ambituuni *et al.* (2014)
Operating capital	Eti *et al.* (2004)
Exchange rates	Wapner (2017), Gary *et al.* (2007)
Profit margins	Gary *et al.* (2007)
Social Factors	
Theft/attacks on pipelines	Siddig et al. (2014), Iwayemi (2008), Wapner (2017), Onuoha (2008)
Illegal refining	Ikelegbe, (2005), Boris (2015)
Security issues	Boris (2015)
Compensations	Izere (2010)
Collusion and sabotage	Akinola (2018), Siddig *et al.* (2014), Brazilian and Onyeji (2012), Wapner (2017)
Grievances and community disputes	Ikelegbe (2005), Obi (2010)
Technical Factors	
Maintenance issues	Iwayemi (2008), Bazilian and Onyeji (2012), Siddig *et al.* (2014)
Ageing facilities	Iwayemi (2008), Ambituuni *et al.* (2014), Eti *et al.* (2004)
Facility design	Eti *et al.* (2006), Turner (1977)
Feedstock supply	Eti *et al.* (2006)
Staff training	Chima *et al*, (2002), Turner (1977)
Staff competence	Chima *et al.* (2002)

Source: Adapted from Iheukwumere *et al.* (2021).

Table 3: Questionnaire participant demographics.

Participants	Size
Targeted Population	200
Respondents	118
Department	
Engineering/Technical	83 (70%)
Administration (HR/Finance/Accounts)	28 (24%)
Managers	7 (6%)
Years of Experience	
3 – 9 years	65 (55%)
10+ years	53 (45%)
Refinery	
PHRC	69 (58%)
KRPC	27 (23%)
WRPC	22 (19%)
Qualifications	
BSC/HND	64 (54%)
MSc	54 (46%)

Source: Author, adapted from Iheukwumere et al., 2021.

Table 4: Interview participant demographics

Participants	Departments	Years of Experience
INT -1	PHRC	11
INT - 2	PHRC	15
INT - 3	PHRC	12
INT - 4	PHRC	15
INT - 5	WRPC	17
INT - 6	WRPC	11
INT - 7	WRPC	12
INT - 8	WRPC	15
INT – 9	KRPC	18
INT - 10	KRPC	11
INT - 11	KRPC	15
INT - 12	Corporate Services	20
INT - 13	Downstream	15
INT - 14	Downstream	18

Table 5: Showing the SEM equations

Nr	Equations
1	POL =~ GovtInterf + Fundissue + Polindec + Govcomm + Manappoint
2	ECO =~ Costspaparts + Operatcap + Excrates + Subissues + Profmargins
3	SOC =~ ThAttackpipe + Illerefin + Securiiss + Compens + Collusandsab + Grievcomdisp + Stakeinvolv
4	TEC =~ Maintissues + Agerefinpl + Limiplcap + Feedssup + Staftra + Stafcompet
5	POL ~ TEC
6	POL ~ SOC
7	ECO ~ TEC
8	POL ~ ECO
9	SOC ~ TEC

{POL=Political factors; ECO= Economic factors; SOC= Social factors; TEC= Technical factors; GovtInterf= Government interference; Fundissue= Funding Issues; Polindec= Political Indecision; Govcomm= Government Commitment; Manappoint = Management appointments; Costspaparts= Cost of spare parts; Operatcap= Operating capital; Excrates= Exchange rates; Subissues= Subsidy Issues; Profmargins= Profit margins; ThAttackpipe= Theft/attacks on pipelines; Illerefin= Illegal refining; Securiiss= Security Issues; Compens= Compensations; Collusandsab= Collusion and Sabotage; Grievcomdisp= Grievances & community disputes; Stakeinvolv= Stakeholder involvements; Maintissues= Maintenance Issues; Agerefinpl= Ageing refinery plants; Limiplcap= Limited plant capacity; Feedssup= Feedstock supply; Staftra= Staff training; Stafcompet = Staff competence}

Table 6: Model test baseline model

	Model
Minimum Function Test Statistic	3.807
χ^2	868.096
Degrees of freedom	225.000
p	< .001

Table 7: Parameter estimates

Relationships			EST	se	z	p	CI (lower)	CI (upper)	std (lv)	std (all)
POL	=~	GovtInterf	1.000	0.000	7.642	< .001	1.000	1.000	0.753	0.840
POL	=~	Fundissue	1.042	0.131	7.961	< .001	0.786	1.299	0.785	0.691
POL	=~	Polindec	1.046	0.112	9.302	< .001	0.826	1.267	0.788	0.778
POL	=~	Govcomm	1.077	0.187	5.754	< .001	0.710	1.444	0.811	0.530
POL	=~	Manappoint	0.396	0.142	2.798	0.005	0.119	0.674	0.299	0.272
ECO	=~	Costspaparts	1.000	0.000	5.345	< .001	1.000	1.000	0.443	0.428
ECO	=~	Operatcap	1.876	0.416	4.514	< .001	1.061	2.690	0.830	0.915
ECO	=~	Excrates	1.293	0.321	4.023	< .001	0.663	1.923	0.572	0.605
ECO	=~	Subissues	1.154	0.338	3.413	< .001	0.491	1.816	0.511	0.440
ECO	=~	Profmargins	1.270	0.325	3.904	< .001	0.632	1.907	0.562	0.566
SOC	=~	Thatackpipe	1.000	0.000	4.432	< .001	1.000	1.000	0.763	0.674
SOC	=~	Illerefin	1.150	0.192	5.983	< .001	0.773	1.527	0.877	0.667
SOC	=~	Securiiss	1.052	0.183	5.756	< .001	0.693	1.410	0.802	0.636
SOC	=~	Compens	0.842	0.146	5.778	< .001	0.556	1.127	0.642	0.639
SOC	=~	Collusandsab	0.779	0.162	4.799	< .001	0.461	1.097	0.594	0.517
SOC	=~	Grievcomdisp	1.103	0.198	5.576	< .001	0.715	1.491	0.842	0.613
SOC	=~	Stakeinvolv	0.931	0.154	6.034	< .001	0.628	1.233	0.710	0.674
TEC	=~	Maintissues	1.000	0.000	5.334	< .001	1.000	1.000	0.927	0.762
TEC	=~	Agrefinplan	0.804	0.098	8.200	< .001	0.612	0.996	0.745	0.758
TEC	=~	Lmtplcap	1.008	0.110	9.127	< .001	0.791	1.224	0.934	0.836
TEC	=~	Feedsup	0.948	0.110	8.625	< .001	0.733	1.164	0.879	0.794
TEC	=~	Staftrain	0.820	0.127	6.458	< .001	0.571	1.069	0.760	0.611
TEC	=~	Stafcompet	0.772	0.110	6.998	< .001	0.556	0.988	0.716	0.658
POL	~	TEC	0.308	0.075	4.094	< .001	0.160	0.455	0.379	0.379
POL	~	SOC	0.147	0.075	1.967	0.049	4.914e -4	0.294	0.149	0.149
ECO	~	TEC	0.232	0.070	3.335	< .001	0.096	0.369	0.487	0.487
POL	~	ECO	1.024	0.259	3.962	< .001	0.518	1.531	0.602	0.602
SOC	~	TEC	0.266	0.093	2.862	0.004	0.084	0.449	0.324	0.324
GovtInterf	~~	GovtInterf	0.238	0.046	5.206	< .001	0.148	0.327	0.238	0.295
Fundissue	~~	Fundissue	0.673	0.101	6.689	< .001	0.476	0.871	0.673	0.522
Polindec	~~	Polindec	0.406	0.067	6.082	< .001	0.275	0.537	0.406	0.395
Govcomm	~~	Govcomm	1.688	0.235	7.188	< .001	1.228	2.149	1.688	0.720
Manappoint	~~	Manappoint	1.113	0.149	7.476	< .001	0.821	1.405	1.113	0.926
Costspaparts	~~	Costspaparts	0.873	0.119	7.324	< .001	0.639	1.107	0.873	0.817
Operatcap	~~	Operatcap	0.134	0.055	2.434	0.015	0.026	0.243	0.134	0.163
Excrates	~~	Excrates	0.566	0.082	6.918	< .001	0.406	0.727	0.566	0.634
Subissues	~~	Subissues	1.087	0.149	7.308	< .001	0.795	1.378	1.087	0.807
Profmargins	~~	Profmargins	0.669	0.095	7.046	< .001	0.483	0.855	0.669	0.679
Thatackpipe	~~	Thatackpipe	0.698	0.111	6.266	< .001	0.480	0.917	0.698	0.545
Illerefin	~~	Illerefin	0.962	0.152	6.318	< .001	0.664	1.261	0.962	0.556
Securiiss	~~	Securiiss	0.946	0.145	6.504	< .001	0.661	1.231	0.946	0.595
Compens	~~	Compens	0.597	0.092	6.487	< .001	0.416	0.777	0.597	0.591
Collusandsab	~~	Collusandsab	0.968	0.138	6.992	< .001	0.697	1.239	0.968	0.733
Grievcomdisp	~~	Grievcomdisp	1.178	0.178	6.626	< .001	0.829	1.526	1.178	0.624
Stakeinvolv	~~	Stakeinvolv	0.606	0.097	6.269	< .001	0.417	0.796	0.606	0.546
Maintissues	~~	Maintissues	0.620	0.098	6.354	< .001	0.429	0.811	0.620	0.419
Agrefinplan	~~	Agrefinplan	0.410	0.064	6.382	< .001	0.284	0.536	0.410	0.425
Lmtplcap	~~	Lmtplcap	0.377	0.068	5.544	< .001	0.244	0.510	0.377	0.302

Relationships			EST	se	z	p	CI (lower)	CI (upper)	std (lv)	std (all)
Feedsup	~~	Feedsup	0.454	0.075	6.078	< .001	0.308	0.601	0.454	0.370
Staftrain	~~	Staftrain	0.970	0.138	7.042	< .001	0.700	1.240	0.970	0.627
Stafcompet	~~	Stafcompet	0.673	0.098	6.899	< .001	0.482	0.864	0.673	0.568
POL	~~	POL	0.105	0.039	2.717	0.007	0.029	0.181	0.185	0.185
ECO	~~	ECO	0.149	0.067	2.244	0.025	0.019	0.280	0.763	0.763
SOC	~~	SOC	0.521	0.141	3.707	< .001	0.245	0.796	0.895	0.895
TEC	~~	TEC	0.860	0.186	4.633	< .001	0.496	1.224	1.000	1.000

Table 8: Selected variables from the path diagram

Factors	Variables
Political factors	Government interference; political indecision; funding issues; managerial appointments
Social factors	Collusion and sabotage
Economic factors	Cost of spare parts; Operating capital; subsidy issues
Technical factors	Maintenance issues; Ageing refineries; limited plant capacity; feedstock supply

Table 9: Overall endogenous and exogenous variables from the quantitative and qualitative methods

Endogenous variables	Characteristics
Funding issues Managerial appointments Collusion and sabotage Operating capital Maintenance issues Ageing refineries Limited plant capacity Feedstock supply Staff training Staff competence	Factors which internally affect the operations of the refineries
Exogenous Variables	
Subsidy issues Cost of spare parts Political indecision Government interference Illegal refining Security issues Exchange rates Stakeholder involvements	Factors which externally affect the operations of the refineries